Wave dissipation and balance - NOPP wave project

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Award Number: N00014-10-1-0383
http://wwz.ifremer.fr/iowaga

LONG-TERM GOALS

Wind-generated waves play a prominent role at the interfaces of the ocean with the atmosphere, land and solid Earth. Waves also define in many ways the appearance of the ocean seen by remote-sensing instruments. Beyond these geophysical aspects, waves also affect human activities at sea and on the coast. The long-term goals of this research are to obtain a better understanding of the physical processes that affect ocean surface waves and their interactions with ocean currents and turbulence, seismic waves, sediments and remote sensing systems, and to improve our forecasting and hindcasting capacity of these phenomena from the global ocean to the nearshore scale.

OBJECTIVES

- Observe and parameterize the dissipation of ocean waves due to breaking or wind-wave interactions
- Advance spectral wave modeling at all (global to beach) scales in a unified framework, in terms of parameterization and numerical developments
- Help the application of wave models to new problems (upper ocean mixing and surface drift, use

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**
4. TITLE AND SUBTITLE **Wave dissipation and balance - NOPP wave project**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Institute of Technology,Dept. of Civil & Environmental Engineering,210 Technology Circle,Savannah,GA,31407**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

of seismic noise data, air-sea gas exchange ...) and use these applications for feedback on the wave model quality

APPROACH

By combining theoretical advances with numerical models, remote sensing and field observations, we investigate the physical processes that affect wind-generated ocean gravity waves. The various dissipative processes that contribute to the spectral wave evolution are isolated by considering geophysical situations in which they are dominant: the long-distance swell propagation in the case of air-sea friction, the evolution of swells on shallow continent shelves in the case of bottom friction, the energy level in the spectral tail in the case of cumulative breaking effects, and the breaking statistics of waves. These require the acquisition of new data using stereo-video techniques, for the spectral levels of waves of 1 to 10 m wavelength, and the statistics of whitecaps. The full model is then confronted to a wide range of observations starting from global altimeter, SAR and buoy data. Alvise Benetazzo is performing the calibration of the stereo system and the reconstruction of sea surface geometries. The determination of the water velocities from the video data is performed by Francesco Fedele and students at Georgia Tech., and the spectral analysis and whitecap detection is performed by students at Ifremer, under the supervision of Fabrice Ardhuin. All the wave modeling effort at Ifremer (theory, parameterization and calibration) is performed by Fabrice Ardhuin and Jean-Francois Filipot.

WORK COMPLETED

Work in FY10 started late due to the late funding of the project. The work focused on two areas, first the development and validation of three-dimensional stereo video reconstruction using the Wave Acquisition System based on Benetazzo (2006) shoreline reflections. and second, the development of the wave modeling with work on dissipation parameterization, forcing fields, andTournadre et al. (2010)

On the analysis of the stereo-video data, we have explored the limits of the retrieval of short waves from the 2009 experiment on the Katsiveli platform, operated by the Marine Hydrophysics Institute of Sebastopol, Ukraine. In that experiment, 2 Mpixel cameras separated by 2.5 m were mounted 12 m above the sea level, resulting in expected errors on the vertical position of the order of 0.2 m at a distance of 50 m. That error was expected to be reduced to less than 0.1 m by the subpixel correlation. We have verified in the reconstructed images that the surface is homogeneous in the field of view, except possibly when sun reflections are important. The wave spectra are self-consistent and spatially homogeneous for distances up to 40 m. After averaging the 3D surfaces over 0.3 s, we obtained reliable estimates of the 3D wave spectrum for wave frequencies less than 1.2 Hz and wavelengths longer than 1 m. These measurements thus provide a unique estimate of the wavenumber spectrum, without ambiguity in the wave propagation direction. The records analyzed from the 2009 experiment were in moderate conditions with winds 6-8 m/s. The observed levels of the non-dimensional and azimuth-integrated wavenumber spectrum

$$B(k) = k^3 \int F(k,\theta) \mathrm{d}\theta \qquad (1)$$

are of the order of 0.006. Further analysis will be performed on new data, to be acquired in October-November 2010, including the analysis of breaking wave properties.

In terms of wave modeling, the effect of Southern ocean icebergs on sea states has been analyzed. The iceberg detection method proposed by Tournadre et al. (2008) using altimeter high-rate waveforms has been applied to the full archive of JASON-1 data, and a statistical parameterization of the distribution of small icebergs has been developed and tested in the WAVEWATCH III model. We have also included a parameterization of shoreline reflection and investigated its impact on directional wave parameters and seismic noise levelsArdhuin et al. (2010b).

A new parameterization of wave breaking dissipation has been developed and tested, it is termed “TEST500”. It uses explicitly the parameterization of breaking probabilities by Filipot et al. (2010), which is designed to be uniformly valid from the deep ocean all the way to the shore. This dissipation parametrization thus replaces the previously distinct “whitecapping” and “depth-induced breaking” by a single expression.

Finally work was also performed on the application of wave modeling for wave-current interaction in three dimensions. A review of this topic with practical tests of various wave-current interaction theories has been submitted to Ocean Modelling (Bennis et al., submitted).

RESULTS

The distribution of icebergs was found to be very variable from year to year, with a strong iceberg population in 2004 in the South Atlantic and an exceptionally high concentration of icebergs in 2008 in the South Pacific. These patterns are well correlated with biases in wave models that do not include icebergs, with a small shift to the East, consistent with the fact that icebergs act like breakwaters and thus lead to smaller wave heights in the downwave direction (to the East) of the largest iceberg concentrations (Figure 1). The proposed parameterization is able to capture that variability, so that the largest model errors that were found in the Southern ocean are much reduced . This was verified for the entire period 2003-2008.

Looking at directional spectra in coastal areas, the spectra are too narrow off the California coast if a reflection of 5 to 20% of the wave energy is not included. These reflection coefficients need to be regionalized are probably frequency and amplitude-dependent Elgar et al. (1994). This level of reflection is consistent with what is needed to produce the proper level of seismic noise due to wave-wave interactions Ardhuin et al. (2010b). These aspects are illustrated by figure 2.

A parameterization of breaking statistics that unifies deep and shallow water waves was proposed and validated with a very limited data set (Filipot et al., 2010). This parameterization shows that the saturation-dependence of breaking wave statistics revealed by Banner et al. (2000) can be interpreted as an increased probability of breaking for waves over a given steepness threshold, in a way similar to shallow water waves observed by Thornton and Guza (1983). This parameterization was further combined with a dissipation rate parameterization to produce a full dissipation source term that explicitly uses breaking statistics Filipot and Ardhuin (2010). This approach was calibrated for deep and shallow water, and provides excellent results in most conditions. This parameterization combined with other terms from TEST441b was termed TEST500. The novelty of this approach is that the same dissipation expression can handle deep water breaking (whitecapping) and the surf zone. Figure 3 shows the model results in the surf zone, and the global scale results are very close to TEST441b, typically much more accurate than with the parameterization by Bidlot et al. (2005). This first successful parameterization based on breaking statistics is an important paradigm shift for the

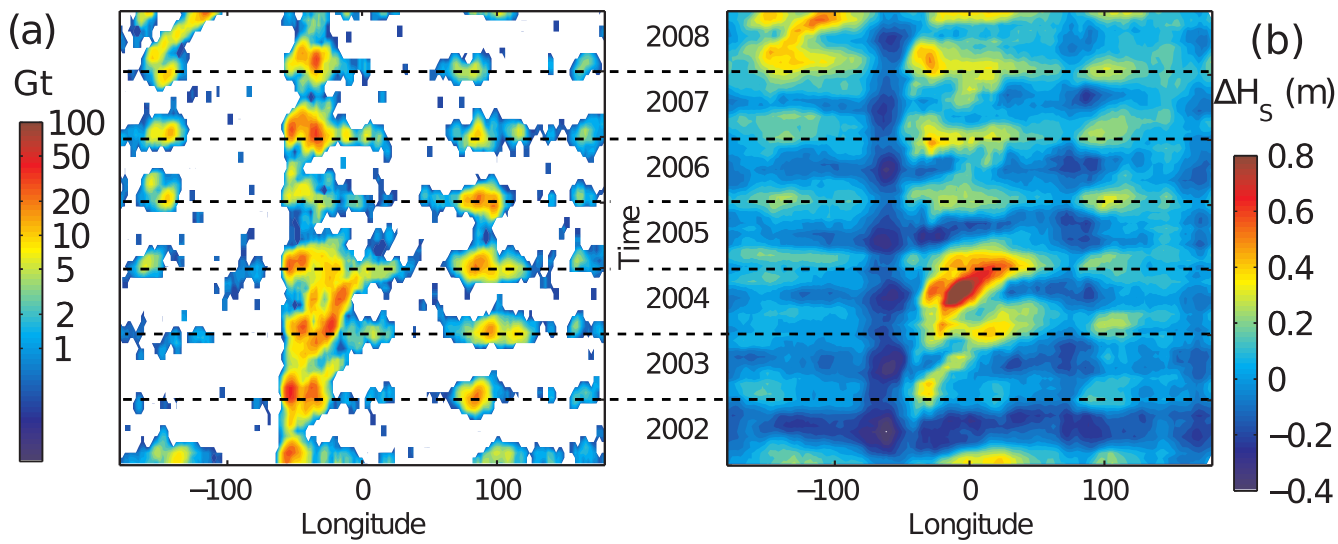

Figure 1: Longitude-time distribution of (a) volume of icebergs less than 6 km^2 in area, as inferred from JASON-1 altimeter data between latitudes 65°S and 45°S, over a 2° sector in longitude (b) bias of the WAVEWATCH III model used at Ifremer (parameterizations by Ardhuin et al. 2010) and forcing by ECMWF winds between latitudes 65°S and 45°S. The icebergs are mostly found in the south Atlantic between the longitudes 50°W to 30°E, and their quantity varies enormously from one year to the next. The year 2008 also has a very large iceberg population in the South Pacific. The model biases can reach 0.8 m over the entire latitude range (65 to 45), with patterns that are very similar to the iceberg patterns.

numerical modelling of wind waves.

IMPACT AND APPLICATIONS

The detection of icebergs and its use for wave modeling is an important aspect for accurate forecasts in the Southern Hemisphere, and may also been applied to the North Atlantic. The combined use of seismic data and numerical wave models offers new opportunities for investigating the Earth structure (tomography) and observing the swell climate in regions where no buoys are deployed. Finally the review of wave-current interaction theories has shown that many theoretical works published in recent years are not self-consistent and it provides guidelines for practical applications to numerical modeling of the coastal ocean.

National Security Improving wave forecasts are relevant to a variety of denfence applications. The most dramatic improvement brought in the operational models by the preasent work is an improved representation of swells which are most relevant for amphibious operations.

Quality of Life The transport of contaminants in the nearshore ocean is largely driven by waves. The capability and understanding of this driving process in three dimensions will certainly lead to improved water quality models.

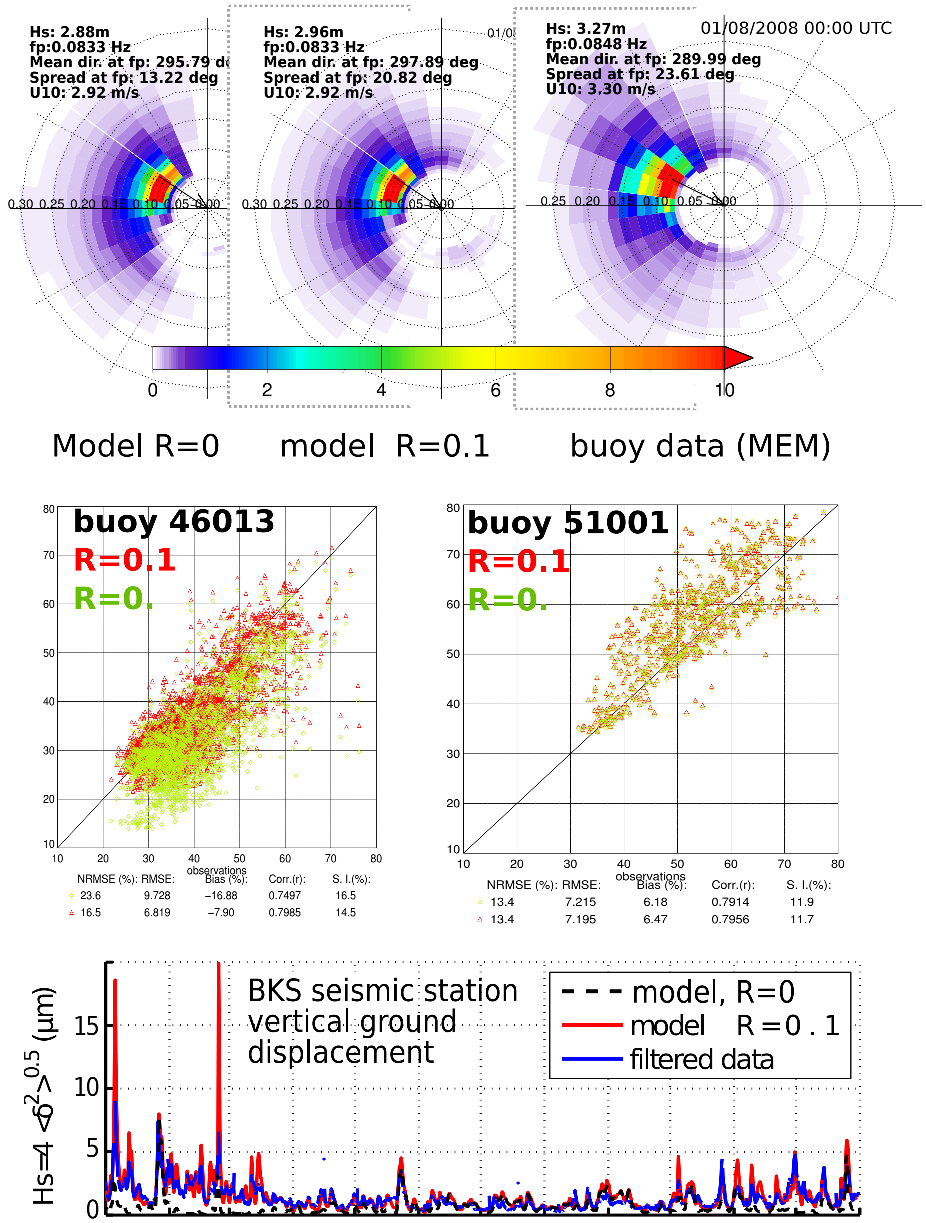

Figure 2: Example of directional wave spectra at the location of buoy 46013 off San Francisco. The modeled spectrum without wave reflection from shore (top left) is much narrower than the observed spectrum (right). A model with a constant 10% reflection (middle) provides a better fit to the data. The observed spectrum was estimated using the Maximum Entropy Method ?. This is validated for the entire year 2008. In order to verify that the problem did not come from the buoy measurements we also modeled the spectra at buoy 51001 (middle right panel) where the coastal reflection has no effect. This importance of reflection is verified by a model of the seismic noise at the Berkeley seismic station (BKS) where a coastal reflection of 10%, or even more in winter, is needed to obtain reasonable seismic energy levels. That last panel is taken from a manuscript submitted to Nature Geoscience.

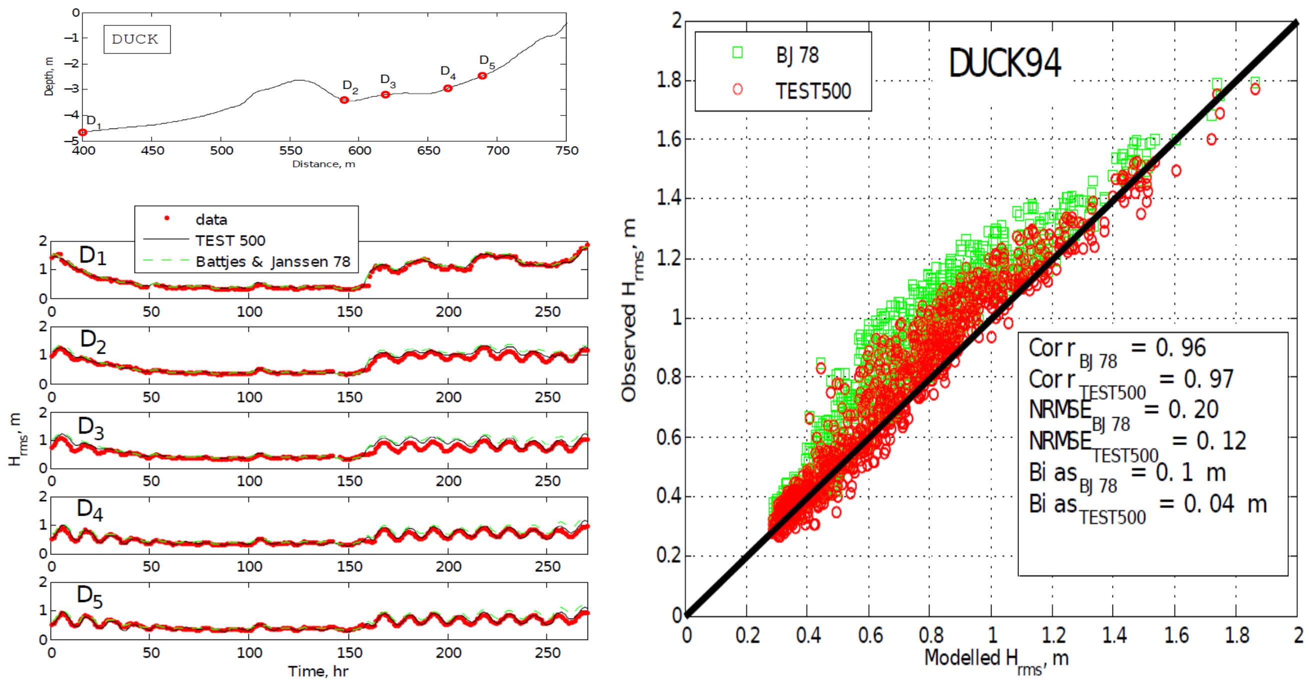

Figure 3: Model results using the TEST500 parameterization compared to observations and the Battjes and Janssen (1978) model. The top left panel shows the beach profile at Duck, during experiment DUCK94. The bottom left panel show the time evolution of the r.m.s. wave height over 10 days of measurements, with a strong reduction of the offshore wave height a the nearshore sensors. This reduction depends strongly on the depth, and is fairly well reproduced by the parameterization by Battjes and Janssen (1978) with a constant breaking coefficient $\gamma = 0.73$*. The new parameterization TEST500 performs.*

TRANSITIONS

The wave model parameterization "TEST437" (also described by Ardhuin et al. 2010) has been successfully implemented at Meteo-France while TEST441b is routinely used at Ifremer for forecasting. In that latter system a constant shoreline reflection of 5% has also been included based on the findings described above. These parameterizations are now considered by NOAA/NCEP for their future upgrade of the operational forecasting system. We will continue helping NOAA/NCEP in testing and implementing these parameterizations.

RELATED PROJECTS

The present "Ocean Waves Dissipation and spectral Balance" (WAVE-DB) shares many of the objectives of the the Integrated Ocean Waves for Geophysical and other Applications (IOWAGA) project, funded by the European Research Council. As a result, results from both projects are reported on the same web pages, where the contribution from each is clearly identified. Whereas WAVE-DB is focused on the development of stereo-video techniques and numerical wave modeling, IOWAGA allows allows a broader perspective with work on remote sensing and seismic noise, which allow a more informed calibration of the numerical wave model. Finally, the WAVE-DB activity is also benefiting from the GLOBWAVE project.

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HONORS/AWARDS/PRIZES

Fabrice Ardhuin was awarded the prize ’Christian Le Provost, Oceanographe’ on October 22, 2009 (joint award by the Cotes d’Armor regional council, CNRS, CNES and the French Academy of Sciences. This award is granted to young oceanographers.